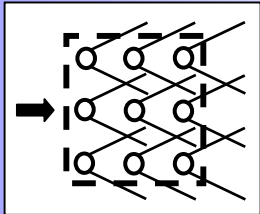


## Lateral Load Tests Of Pile Groups Lead to Improved Design Recommendations

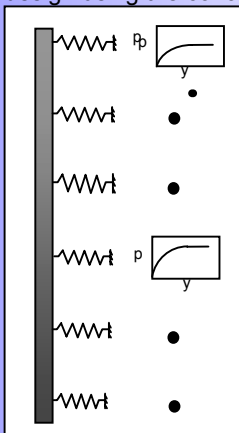
**RESULTS:** *The Caltrans' GeoResearch Group (GRG) recently joined several other states in sponsoring a series of full-scale lateral load-tests on several pile groups at a test site in Salt Lake City, Utah. These tests have provided key data needed to assess the impact of group size and pile spacing on lateral capacity and stiffness.*

### Why We Pursued This Research

A pile foundation's lateral capacity and stiffness can be critically important to the design of highway bridges subject to earthquake loading. Obtaining a desired level of lateral capacity can be a controlling design issue, particularly in soft soil conditions. It has long been recognized that the lateral capacity of a pile group is less than the sum of individual pile capacities within that group. This behavior can be attributed to overlapping shear zones within the group. A pile located closely behind another cannot develop the same lateral resistance as if isolated, since the surrounding soil provides resistance for both piles instead of just one.



Laterally loaded piles are most commonly modeled in design using the concept of "soil springs". These springs account for the lateral resistance of the soil as a function of displacement. They are typically nonlinear and are characterized by p-y curves which describe the springs load "p" as a function of deformation "y".



As it is much easier to perform lateral load tests on single piles rather than pile groups, procedures for developing p-y curves were derived from lateral load-tests on single piles. To apply these curves to pile groups, a scale factor is applied to the "p" component (i.e. the load component) of the p-y curve. This scale factor is commonly referred to as the "p-multiplier".

Prior to this testing program, p-multipliers were based largely on the research results of a handful of lateral group tests performed in the field and on the centrifuge. A listing of these tests and their key features is provided in Tables 1 and 2.

| Reference       | Group Size | Pile Sp. | p-multipliers (by row) |     |     |     |
|-----------------|------------|----------|------------------------|-----|-----|-----|
|                 |            |          | 1                      | 2   | 3   | 4   |
| Meimon (1986)   | 3x2        | 3d       | 0.9                    | 0.5 | -   | -   |
| Brown (1987)    | 3x3        | 3d       | 0.7                    | 0.6 | 0.5 | -   |
| Brown (1988)    | 3x3        | 3d       | 0.8                    | 0.4 | 0.3 | -   |
| Townsend (1997) | 4x4        | 3d       | 0.8                    | 0.7 | 0.3 | 0.3 |
| Rollins (1998)  | 3x3        | 3d       | 0.6                    | 0.4 | 0.4 | -   |

Table 1: Summary of p-multipliers based on previous full-scale lateral pile group tests. (Modified from Rollins et al., 2002)

| Ref.           | Grp Size | Pile Sp. | p-multipliers (by row) |     |     |     |     |     |
|----------------|----------|----------|------------------------|-----|-----|-----|-----|-----|
|                |          |          | 1                      | 2   | 3   | 4   | 5   | 6   |
| McVay (1995)   | 3x3      | 3d       | .65                    | .45 | .35 | -   | -   | -   |
|                | 3x3      | 3d       | .80                    | .45 | .30 | -   | -   | -   |
|                | 3x3      | 5d       | 1.0                    | .85 | .70 | -   | -   | -   |
| McVay (1995)   | 3x3      | 3d       | .80                    | .40 | .30 | -   | -   | -   |
|                | 3x4      | 3d       | .80                    | .40 | .30 | .30 | -   | -   |
|                | 3x5      | 3d       | .80                    | .40 | .30 | .20 | .30 | -   |
|                | 3x6      | 3d       | .80                    | .40 | .30 | .20 | .20 | .30 |
|                | 3x7      | 3d       | .80                    | .40 | .30 | .20 | .20 | .20 |
| Garnier (1998) | 1x2      | 2d       | -                      | .52 | -   | -   | -   | -   |
|                | 1x2      | 4d       | -                      | .82 | -   | -   | -   | -   |
|                | 1x2      | 6d       | -                      | .93 | -   | -   | -   | -   |

Table 2: Summary of p-multipliers based on previous centrifuge tests. (Modified from Rollins, et al., 2002)

As can be seen in Table1, field test data only exist for 3d pile spacing and, except for one test, 3x3 pile groups. This test program sought to extend the range of field test data by performing lateral load tests on groups with pile spacing ranging from 3d to 5.6d and sizes ranging from 3x3 to 5x3.

### What We Did

The Geo Research Group joined several other states to sponsor a series of lateral group load tests in Salt Lake City, Utah. These load tests and subsequent analyses were performed by Professor Kyle Rollins of Brigham Young University.

Four static, free head, lateral group load-tests were performed:

- 3x3 group, 5.6d spacing, 12.75-in pile diameter
- 4x3 group, 4.4d spacing, 12.75-in pile diameter
- 5x3 group, 3.3d spacing, 12.75-in pile diameter
- 3x3 group, 3.0d spacing, 24-in pile diameter

## Research Results

Back-calculated  $p$ -multipliers from these tests are plotted as a function of pile spacing in Figures 1 and 2. For reference, results from previous full-scale tests are also shown.

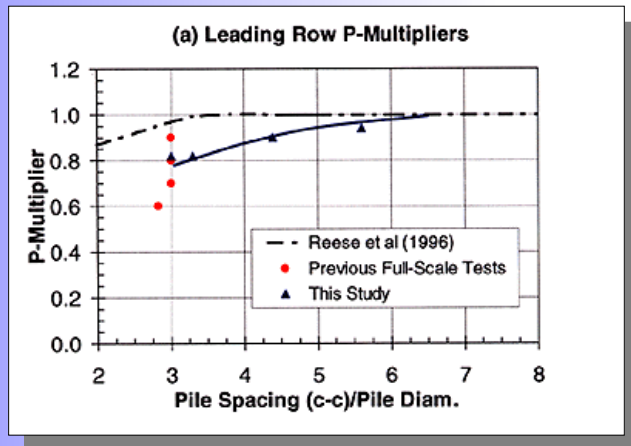


Figure 1: Back-calculated  $p$ -multipliers for leading row piles. (Rollins, et al., 2002)

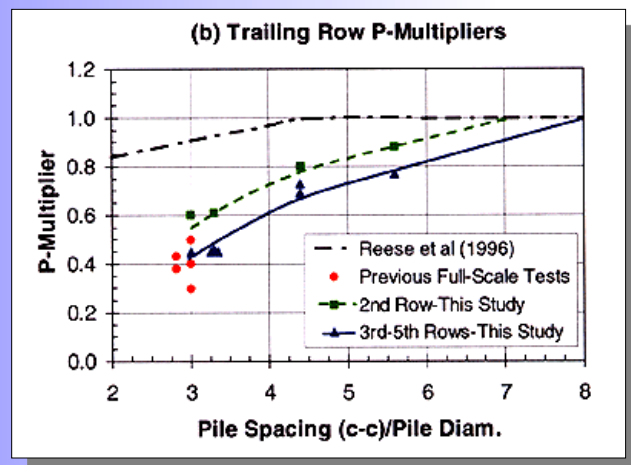


Figure 2: Back-calculated  $p$ -multipliers for trailing row piles. (Rollins et al., 2002)

The results from this study fall near the center of the results from previous studies performed at 3d spacing. As pile spacing increases beyond 3d, the drop off of the group effect follows a consistent trend. Extrapolation of this trend suggests negligible group effect at pile spacings exceeding 7 to 8d.

Other important findings include the following:

- Loads across a pile row were approximately the same (i.e., interior and exterior piles carried about the same load. Methods based on elastic theory predict larger loads on exterior piles.)
- The 4<sup>th</sup> and 5<sup>th</sup> pile rows carried about the same load as the 3<sup>rd</sup> row. This suggests that  $p$ -multipliers reach a limit after about 3 rows.
- Group reduction effects typically increased as deflections increased to about 0.5 to 1.0-inch but then remained constant out to deflections of 3 or 4-inches (the limits of the testing).
- The  $p$ -multiplier back-calculated for the 24-inch diameter piles at 3d spacing was essentially the same as the  $p$ -multipliers for the 12.75-inch diameter piles at 3.3d spacing. This suggests that  $p$ -multipliers are not strongly affected by pile diameter.
- $P$ -multipliers recommended in the program GROUP under-predict the group effect when compared to actual field test results.

## Recommendations for Design

Based on the results of this test program and that of previous efforts identified in Table 1, the GRG suggests that reasonable  $p$ -multipliers for the common design case of 3d pile spacing are as follows:

|                   |      |
|-------------------|------|
| Row 1:            | 0.75 |
| Row 2:            | 0.55 |
| Row 3 and larger: | 0.40 |

For pile spacing other than 3d the above multipliers should be modified in accord with Figures 1 and 2.

Although the Salt Lake City load-tests occurred in mostly clay soils, review of the tests reported in Table 1 suggests that  $p$ -multipliers are not strongly soil type dependent and that the recommended values above are appropriate for both clay and sandy soils.

When using the program GROUP, instead of using options for automatic  $p$ -multiplier generation, consider specifying multipliers consistent with the recommendations above.

## Reference

Rollins, K.M., Olsen, R.J., Egbert, J.J., Olsen, K.G., Jensen, D.H., Garrett, B.H.; "Response, Analysis, and Design of Pile Groups Subjected To Static & Dynamic Lateral Loads", *Draft Final Report*, Jan. 2002.

## For More Information on GeoResearch Projects

Cliff Roblee (916) 227-7183 [cliff.roblee@dot.ca.gov](mailto:cliff.roblee@dot.ca.gov)  
Tom Shantz\* (916) 227-7245 [tom.shantz@dot.ca.gov](mailto:tom.shantz@dot.ca.gov)  
Loren Turner (916) 227-7174 [loren.turner@dot.ca.gov](mailto:loren.turner@dot.ca.gov)  
Ali Porbaha (916) 227-7161 [ali.porbaha@dot.ca.gov](mailto:ali.porbaha@dot.ca.gov)  
Brian Chiou (916) 227-7151 [brian.chiou@dot.ca.gov](mailto:brian.chiou@dot.ca.gov)

\* Primary contact for more information on this project